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Challenging agroecology through the characterization of farming practices' diversity in Mediterranean irrigated areas

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Abstract

Identifying locally adapted and adopted efficient practices can be a step towards the agroecological transition of irrigated plains of the Southern Mediterranean region. However, these types of practices - often little known - are drowned within a wide range of practices. The objective of this study was, first, to elaborate a method to describe this diversity in a semi-arid irrigated landscape, at both the plot and farm scales; second, to show the main characteristics of these types of crop management; and third, to question their sustainability according to agroecological principles. To do so, this paper focused on Southern Mediterranean irrigated cropping systems as i) studies on management routes are scarce with regard to this region; ii) irrigated landscapes are known for their high level of natural, technical and financial constraints, often favoring more intensive farming practices regarding chemical inputs. A series of semi-directive interviews were conducted in order to assess farmers' management of chili-pepper-based (*Capsicum annuum*) cropping systems, a widespread crop in the Merguellil plain, Central Tunisia. The "Typ-iti" method, combining multivariate analysis, clustering and association rules, was used to characterize the diversity of technical management routes (TMR) of these systems. The environmental sustainability was qualitatively accessed by classifying the clusters of TMRs obtained according to their potential impact on natural resources. Then, these management routes were qualitatively associated to some farm structural indicators, to analyze their diversity at the farm level. These enabled to distinguish a gradient of farming practices and characteristics, respectively at both plot and farm scales relative to environmental impacts. The study showed that some agroecology-compatible TMRs coexisted with conventional TMRs for chili-pepper-based cropping systems. Our method characterized three main groups: i) a group of intensive TMRs regarding chemical input powered especially by tenant farmers, ii) an intermediary group iii) a moderate group powered by land owners. Throughout these main groups, seven types of

TMRs were described. These were always comprised of both agroecology and non-agroecology-compatible technical operations. This coexistence of diversely impacting practices challenges agroecology in multiple ways. Fertilization management appeared as a major issue in the study zone, often resulting in high applied doses. These findings could allow actors in charge of agriculture to better focus their action. However, the study did not take into account the outputs of the studied systems, so that their productivity and environmental impacts have not yet been assessed in a quantitative manner. For future studies, the paragons obtained from our analysis are typical cases that could be studied for such a purpose.

Key words: cropping systems; environmental impact; irrigation; Merguellil plain; Tunisia; typology.

1 Introduction

The Southern Mediterranean region is vulnerable to climatic hazards and at a high risk of severe degradation of both biodiversity and agricultural production, due to the combination of climate change and conventional farming practices (Migliorini et al., 2018; MedECC, 2020). New patterns of action would be required to address these issues simultaneously (Caron et al., 2014), with an acute need to implement new agricultural models combining biodiversity conservation, climate change adaptation and food production. Agroecology, which is the production of significant amounts of food, valorizing ecological processes and ecosystem services and integrating them as essential factors in the improvement of practices (Gliessman, 1990; Altieri, 2008. Wezel et al., 2014), with its three pillars i) efficiency increase, ii) substitution of inputs, iii) system redesign or diversification (Hill, 1998; Wezel et al., 2014; Duru et al., 2015; Ci and Ma, 2016), could be a pathway for a more sustainable agriculture in the Southern Mediterranean region (Horlings and Marsden, 2011). Agroecology suggests that actions to achieve this goal must be adapted to each agrosystem and take into account local conditions.

Although recent literature is appearing on the subject (for example, de Lattre-Gasquet et al., 2017; Ameur et al., 2020), little is still known on the potential of agroecological concepts to address these issues in this region of the world, in particular within irrigated areas. In the North African irrigated areas, agriculture is strongly based on the use of external productive factors (especially chemical inputs). Efficiency increases and input substitutions could appear as a first step of action towards a more sustainable agriculture. This can start by a widespread adoption of local efficient and environmental-friendly farming practices. In this paper, it is hypothesized that strong social, economic and environmental constraints in irrigated areas (Jamin et al., 2011) might enable a diversity of farming practices. Could more environmental-friendly farming practices arise from this local diversity? In what extent are these practices already present or how can they be developed in Mediterranean irrigated systems? In a first step to answer these questions, the objective of this study was to i) describe the possible diversity of farming practices in a typical North African irrigated area and ii) identify the existence of environmental-friendly management routes, and the types of farmers implementing them. The paper seeks to provide a complete and comprehensive description of existing farming practices at the plot and farm-scale, enhancing their diversity, and putting forward in particular potential agroecological practices, but does not undertake a quantitative evaluation of their agronomic or environmental impacts.

Access to irrigation is a recurrent demand of smallholder farmers in North Africa, due to expected productivity and income increases, compared to rainfed systems. Progress has been made in this matter, with the development of individual pumping systems giving access to the aquifers. The number of pumping wells has indeed increased drastically in North Africa, irrigating more than 1.75 million ha in Algeria, Morocco and Tunisia (Leduc et al., 2004; Kuper et al., 2017). The Merguellil plain in Central Tunisia is a typical example. In parallel, public policies sought to encourage water economy and have promoted the development of modern irrigated systems, resulting in a wide adoption of drip irrigation. But through fertigation, the latter also facilitates increased applications of nutrients, at a certain environmental cost due to pollutions (Burkhalter and Gates Timothy, 2005; Poussin et al., 2008; Laib et al., 2018). However, it has been shown that the modern irrigated systems could also enable a better management of nutrients and inputs (Benouniche et al., 2014; Al-Ghobari and Dewidar, 2018; Sandhu et al., 2019).

In addition, smallholder farmers such as those in the Merguellil plain, can design environmental-friendly farming practices, more adapted to their local social, economic and environmental conditions, allowing them to achieve their production goals, depending on neither chemical inputs nor pesticides (Altieri, 2008). To achieve this, farmers often combine different strategies as part of a usual household management scheme (Pinto-Correia et al., 2017). Thus, the farmer makes choices through diverse ways of farming. So, it is fair to ask whether diversity is one of the main characteristics of these farming practices at the territorial scale.

In this paper, we elaborate a method to describe the diversity of farming practices in the Merguellil plain – a location of multiple researches, characterized by its dynamic and diverse agricultural system (Azizi et al., 2017) – at both the plot and farm scales, by analyzing local practices. This can be achieved by characterizing existing technical management routes (Renaud-Gentié et al., 2014; Salou et al., 2017), noted TMRs, and identifying a gradient between chemically-intensive and more environmental-friendly TMRs.

TMRs are the logical and ordered succession of technical operations (TO) aiming to control the environment and obtain a given production (Sébillotte, 1974). So far, investigations that integrate all the TMRs steps to describe existing cropping systems in small-scale household agriculture are scarce (Renaud-Gentié et al., 2014, Czyrnek-Delêtre et al., 2018), even the more in Mediterranean irrigated areas. Multiple studies characterizing farming systems and crop management practices exist (Bellon et al., 2001; Köbrich et al., 2003; Maton et al., 2005; Poussin et al., 2008; Blazy et al., 2009; Ibidhi et al., 2018). These studies used either statistical analysis or participatory and expert-based methods. These methods have limits as they i) only identify the most relevant character of each TMR; and ii) do not describe the logical links between TOs (Renaud-Gentié et al., 2014). For instance, only quantitative data on farming practices were used to describe the diversity of coffee-based agroforestry systems in Costa-Rica (Meylan et al., 2013). Another study, examining the variability of farm structure and farming practices, highlighted both low input and intensive systems, but was limited to the analysis of water and N use, pest and crop residue management (Caballero, 2001).

The paper, focused on chili-pepper (*Capsicum annuum*) as a cropping system model, proceeds in the following way. First, it develops the approach used to assess farmers' practices. Then, it describes the technical operations, their interconnexions within TMRs, and their (non-)agroecological orientation and (non-)association to farm types. Finally, it discusses this diversity of farming practices in the light of co-existing irrigation, pollution and agroecology stakes, and how these conditions challenge the implementation of agroecological practices in Southern Mediterranean irrigated areas.

2 Materials and methods

2.1 Study site

The study took place in the downstream plain of the Merguellil catchment in Central Tunisia (Fig. 1). The latter, covering over 700 km^2, is part of the large and flat Kairouan alluvial plain which extends almost over 3000 km^2 (Leduc et al., 2007). The climate is semi-arid with 300 to 500 mm of total annual rainfall. The downstream plain is almost entirely used for agricultural purposes with a combination of irrigated and, to a lesser extent, non-irrigated agriculture. Most agricultural water withdrawal, consuming 80% of the total extracted water per year (Poussin et al., 2008), takes place in this downstream zone where a very high density of drilling is observed (Massuel et al., 2017).

Cropping systems are characterized by a wide variety of crops, including olive groves and fruit orchards, alone or intercropped; watermelon (*Citrullus lanatu*) and melon (*Cucumis melo*), tomato (*Solanum lycopersicum*), chili-pepper (*Capsicum annuum*) and other winter and summer vegetables (Poussin et al., 2008; Ameur et al., 2020). Farm structures are also diverse as far as total area, level of equipment and cropping systems are concerned. The agricultural sector is very dynamic, characterized by significant changes in farms' production structures and orientation during the last decade. These changes were stimulated by i) a facilitated water access for initially rainfed farms; ii) the adoption of irrigated horticultural crops for some farmers; iii) the reduction of annual crops, replaced by irrigated olive groves and fruits orchards for others (Azizi et al., 2017). As one of the most widespread crops, present in most of cropping systems, pepper-based cropping systems were used to represent the irrigated horticultural crops in this area.

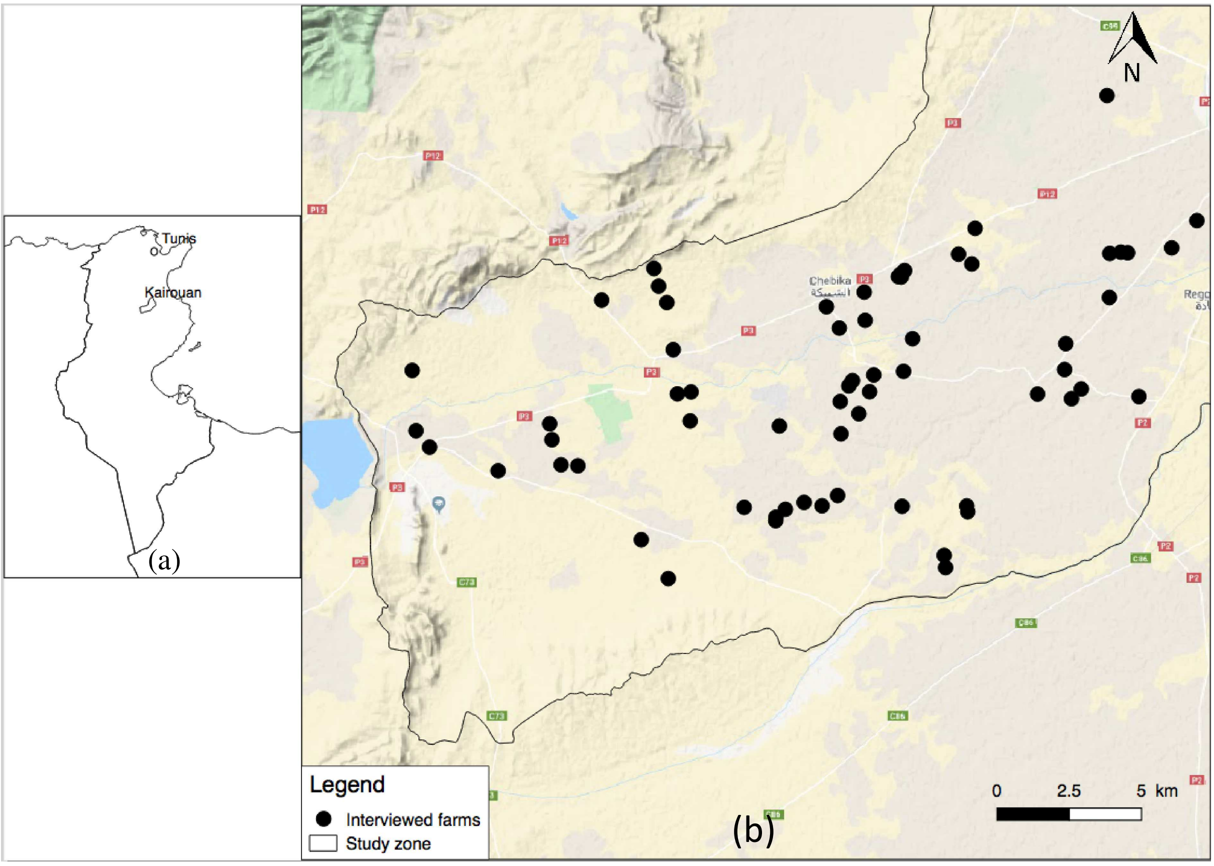

Fig. 1 (a) Location of the case-study site: the Merguellil downstream plain in Central Tunisia; (b) interviewed farms (black dots).

2.2 Methodological approach

In this paper, farming practices include the ways of farming at both plot and farm scales. The TMR (Technical Management Routes) is a succession of TOs (Technical Operations) applied to a chili-pepper plot. A TO refers to an action or a choice performed by the farmer on the plot. Agroecology-compatible TOs or practices refer to TOs compatible with agroecology. (Non)-environmental-friendly TMRs refer to TMRs compatible with agroecology or not.

The global approach, allowing to finely characterize the TMRs, give indications on their sustainability and links to farm characteristics, consisted in four successive steps: i) sampling and data collection through field surveys, ii) database and variables construction, including a characterization of their potential environmental impact (in a qualitative manner), iii) statistical analysis including data mining, enabling the description of different clusters of TMRs, and iv) the identification of the types of farms implementing each type TMR. These steps are described here below in detail and in Fig. 2.

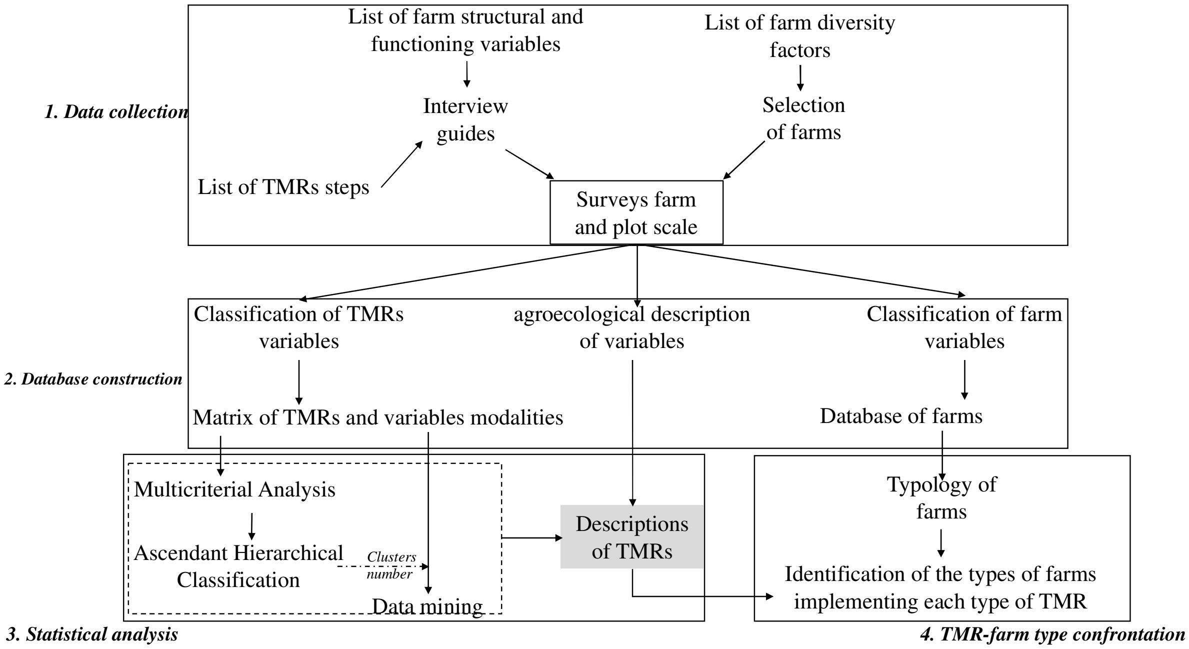

Fig. 2: Methodological approach.

2.2.1 Sampling and data collection

Data collection was carried out through semi-directive interviews with farmers in Spring 2018 and was conducted in three phases. First, 65 farms were chosen for their diversity, not only in their structure (crop types, farm size, land tenure), but also in their localisation throughout the Merguellil plain. A wide range of farm sizes was covered (1-75 ha). Farm selection was actor- and expert-based, or by direct observation. Second, a series of semi-directive interviews with farmers were conducted, in order to apprehend the organization and functioning of the farms. These interviews concerned not only crop types and successions, but also labor origin (family or temporary), land tenure (tenants, landlords, sharecroppers), water supply sources (individual drilling, collective network), and crop management (seed origin, chemical fertilizers, plant protection products). This allowed a confrontation of management routes to farms structures. Third, a series of detailed interviews were conducted on the pepper crop farming practices, using the TMR concept applied to both farmers' strategic and operational decisions. The strategic decisions are made at the beginning of the season and concern plot configuration, types of association, choice of crop varieties and planting date, while the operational decisions concern the technical steps of transplantation, tillage, irrigation, pest management, fertilization and harvesting. A list of TOs related to all the steps of a TMR was pre-established through expert-knowledge and was pilot tested with a few farmers.

Data acquisition on the TMRs applied to chili-pepper was carried out on 45 plots. To achieve so, a minimum of two interviews of one to two hours with each the farmer was required in order to correctly understand the functioning of the cropping system. Interviews, combined with direct observations, were face-to-face and took place within the farm, with audio record and field notes. When required, additional information were obtained by phone call.

2.2.2 Database and variables construction

Collected data were transcribed into a table of TMRs, where each TO of the TMR was described by its modalities. The TOs represent the variables used for statistical analyses. The modalities of a TO are the different values it can take. Data were both quantitative and qualitative. The quantitative data were first transformed into qualitative variables, using the "natural occurring division" approach (Husson et al., 2017), based on the analysis of the histograms of the observations, in order to maintain the modalities as observed. Two to four modalities were constructed depending on TOs. To avoid redundant information and characterize the diversity of TMRs, TOs with a single common modality to all farmers were not taken into account in the analyses.

2.2.3 Qualitative assessment of the potential environmental impact of farming practices

In order to assess the potential environmental sustainability of the TMRs, the modalities of each TO were qualitatively classified according to their potential impact on natural resources, using three levels: TOs with a potentially positive environmental impact (e.g. no pesticide application), TOs potentially harmful (e.g. high value of N input) and TOs with no evident positive nor negative first-order impact (e.g. planting date). TO modalities were classified relative to each other, assuming a gradient of environmental impacts rather than an absolute value. Their attribution into each level was based on described agroecological practices in the literature (Wezel et al., 2014; Ameur et al., 2020), and expertise. A rating was assigned to each TO: +1 for TOs with potentially positive environmental impact (agroecology-compatible), -1 for potentially harmful (non-agroecology-compatible) TOs, 0 for TOs with no evident positive nor negative first-order impact. TOs were classified as harmful or not based its potential contribution to the stages of the ESR (Efficiency increase, Substitution, Redesign) conceptual framework, and criteria presented in Table 1. This scoring was adapted from an approach of scoring farming practices for a qualitative assessment of ecological impacts of cropping systems (Bohanec et al., 2008). After statistical analysis, a total rating was computed by summing up the scores of the TOs significantly linked to each cluster, giving a potential level of environmental impact of the cluster. Four degrees of impact were defined for farming practices: high (non-environmental-friendly), neutral (intermediary), medium low (moderately environmental-friendly), and low (environmental-friendly).

Table 1: criteria used to classify TOs as 'harmful' or agroecology-compatible. Each TO is categorized according to the ESR conceptual framework. E= Efficiency increase; S = Substitution; R = Redesign

TMR steps	TO	ESR	Criteria
Tillage	Weeding / Hoeing	E, S	Reduces energy consumption for seedbed preparation and soil compaction.
Variety choices and crop spatial distribution	Variety	E, S	Increase in pest control, and resistance to water stress. Reduction of fertilizer or pesticide use.
	Planting strategy	-	-
	Association with leguminous	E, S, R	Increase in land productivity. Reduction of pest and disease impact. Improvement of nitrogen content of soils.
	Association with trees	E, S, R	Increase in land productivity. Decrease in nutrient leaching and soil erosion. Diversity of production: wood (timber, firewood), Protection of crops from intense solar radiation and wind.
	Association with cucurbitaceae	E	Increase in land productivity.
Irrigation	Water stress	E	Enhance plant water uptake. Decrease water use.
Pest management	Number of pesticide applications	S	Pest pressure control with limited use (or no use) of pesticides.
Fertilization	Organic fertilization mode	E, S	Reduction of chemical fertilizer use. Reduction of energy consumption for transport when using on-farm manure or from nearby.
	N (kg.ha^{-1})	E, S	Reduced fertilizer use increases efficiency. Reduction of risk of ground and surface water contamination.
	P (kg.ha^{-1})	E, S	
	K (kg.ha^{-1})	E, S	
	Ca (kg.ha^{-1})	E, S	
	Mg (kg.ha^{-1})	E, S	
	Ternary fertilizer leaf application	E, S	
	Synthetic bio-stimulant use	E, S	Reduction of fertilizer use. Improvement of nutrient availability.
Harvesting	Harvest regularity	-	-
	Crop residue management	E, S, R	Organic matter and nutrient recycling.
	Crop color harvest	-	-

2.2.4 Statistical analysis using the "Typ-iti" method

The "Typ-iti" analytical method (Renaud-Gentié *et al.* 2014) was used to characterize the diversity of TMRs for pepper cultivation. Combining three different statistical tools, the former was realized through three phases: i) a multiple correspondence analysis (MCA) summarizing the relationship between plots and TOs' modalities ii) an ascending hierarchical classification (AHC) enabling the grouping of TMRs into separate clusters, within which the TMRs are relatively similar, finally, iii) a data-mining analysis to generate association rules between modalities (Agrawal et al., 1993). The results of all the statistical analyses are synthetized in a table describing each type of TMR.

MCA was first applied to the TO table. Then, using the resulting coordinates of TMRs on the MCA axis, the AHC was performed by the Ward method, to obtain the clusters. The number of clusters, first chosen on the basis of the explained inertia rate, was consolidated through the calculation of the optimal number of clusters using K-Means partitioning. The description of clusters was, first, based on chi2 correlation tests. A modality was linked to a cluster if its p-value < 0.05. Second, a TO modality was described as a cluster's character if i) it was present in more than 50% of the cluster's TMRs, or ii) if more than 50% of all TMRs of the dataset were present in the cluster's TMRs in the case of significant p-value.

Finally, to have a complete description of TMRs, a data-mining analysis was performed. It consisted in mining association rules, which are combinations of modalities within TOs. This allows to identify additional TOs significantly linked to TMRs and not shown by the previous MCA analysis, because they were not specific to groups. Rules are defined as a succession of TO modalities common to a minimum defined number of TMRs in a same cluster. They were interpreted based on three criteria: the support (S), the confident (C) and the adjusted support, noted S_a (Renaud-Gentié et al., 2014). The support is the frequency of occurence of a rule. Let us consider A, a succession of k TOs ($k > 0$), and B another succession of n TOs ($n > 0$); for A and B, the support of the rule $A \Rightarrow B$ is computed as follows:

$$S\ (A \Rightarrow B) = P(A \cup B)$$

A minimum support S_m was calculated by dividing the number of TMRs in the cluster comprising the lower number of individuals over the total sample size. The confident of the rule $A \Rightarrow B$ is the percentage of rules containing A and B.

$$\text{Confidence } (A \Rightarrow B) = P(B|A)$$

The adjusted support is the support relative number of TMRs contained in a cluster.

$$Sa\ (A \Rightarrow B) = P(A \cup B)*(\text{total sample size})*(\text{number of TMRs of the cluster})^{-1}$$

A rule was considered as linked with a cluster if $S \geq S_m$, C=1 and $S_a \geq 0.5$. An S_a of 0.5 meant that 50% of individuals in the cluster should contain the rule.

For each cluster, the four longest rules were represented and compared to MCA and AHC descriptions. In addition, the data-mining also describes clusters' similarity and homogeneity, as these increase with number and length of rules. The combined MCA, AHC and data-mining analysis led to a complete description of TMRs for each cluster. These typical TMRs were finally compared to the most representative individual of each cluster, called the paragon, obtained in the clustering phase, to assess in what extend they match with actually existing TMRs.

The statistical analyses were performed with the R software (R Core Team, 2019). MCA and data-mining were computed using the FactoMineR (Husson et al., 2020) and Arules (Hornik et al., 2005) packages, respectively.

2.2.5 Identifying farm types associated to each cluster

This final step consisted in confronting the typical TMRs to farm structural information, in order to qualitatively link the respective TMRs and their potential environmental impact to farm-level characteristics.

A contingency table of plots and farm types was obtained, by cross-tabulating the TMRs of each cluster with the characteristics of the farms with which they were associated. The structural data of farms were used to classify them regarding ten criteria, representing farm characteristics, typical of the case-study-site (Azizi et al., 2017; Poussin et al., 2008). These pertained to i) access to water ("individual drilling", "collective network"), ii) access to land ("direct access" for land owners, 'indirect access" for tenants, "indirect & indirect access" for tenants who also owned some land), and iii) types of production ("grain farming", "cucurbitaceae", "leguminous", "arboriculture" and "livestock).

3 Results

Results, organized in five sections, first present the various TOs (Technical Operations) found in the study region, then describe the statistical analyses for each specific phase. Stemming from this step-by-step depiction, the overall characteristics of the TMRs (Technical Management Routes) are then presented. Finally, these are analyzed in the light of associated structural farm characteristics.

3.1 Technical operations used for statistical analysis

Six TMR steps were identified, constituted of one to eight TOs (variables) each (Table 2), resulting in a total of nineteen TOs. Variety type and crop spatial distribution were the strategical choices of the farmer. Tillage, irrigation, pest management, fertilization and harvesting were tactical and operational choices. As far as soil preparation is concerned, farmers had the same practice of ploughing and leveling. Two choices for the varieties were possible, with on the one hand local varieties of chili-pepper, enabling seed reuse, purchased from a nursery or grown on-farm; and on the other hand, hybrid varieties exclusively purchased, yearly, from professional nurseries.

In addition, different strategies of planting date and spatial arrangements were observed. Chili-pepper could be associated to leguminous, watermelon or melon and olive groves. Data concerning overall water consumption, unavailable, were not taken into account. Two irrigation strategies were however observed, with the use – or not – of water stress periods, ranging from 10 to 30 days, which « allow good root development », according to farmers. Farmers have access to a wide range of plant protection products, applied on the basis of trade names rather than active substances. As far as fertilization is concerned, nutrient supply was mainly by fertigation. Foliar and soil applications were also common, depending on the strategies and product. Further, the harvest was very dependent on workforce and sale prices. The latter determined the dates and color of fruit at harvest.

Table 2: Technical operations (TO), and their defined modalities, used for the MCA and next steps of the study. Each TO has two to four modalities. NOFA = No Organic Fertilizer Application, SAP = Soil Application before Planting, SAPF = Soil Application before Planting and Fertigation, SAPP= Soil Application before Plouging and Planting. Early planting =before April; in-season planting = from April to May; off-season planting = from June to August. * less than 15 days after planting; ** more than 15 days afetr planting. NA: No answer

TMR steps	TO	Modality 1	Modality 2	Modality 3	Modality 4
Tillage	Weeding / Hoeing	Early*	Late**	No tillage	
Variety choices and crop spatial distribution	Variety	Hybrid	Local		
	Planting strategy	Early planting	Season planting	Off-season planting	Regrowth
	Association with leguminous	No	Association	Relay	
	Association with trees	No tree	Extensive density	Intensive density	
	Association with cucurbitaceae	Yes	No		
Irrigation	Water stress	Yes	No		
Pest management	Number of pesticide applications	0	[1,4]	(4,8]	> 8
Fertilization	Organic fertilization mode	NOFA	SAP	SAPF	SAPP
	N (kg.ha^{-1})	(0,50]	(50,100]	(100,150]	(150 -300]
	P (kg.ha^{-1})	0	(0,60]	(60,120]	(120 - 200]
	K (kg.ha^{-1})	0	(0,20]	(20,40]	(40 – 100]
	Ca (kg.ha^{-1})	0	(0,20]	> 20	
	Mg (kg.ha^{-1})	0	(0,5]	(5,20]	
	Ternary fertilizer leaf application	Yes	No		
	Synthetic bio-stimulant use	Yes	No		
Harvesting	Harvest regularity	Continue	Stepped		
	Crop residue management	NA or late return	Early return	grazing and restitution	
	Crop color harvest	Green	Red	Green and Red	

3.2 MCA and clustering

The MCA was performed on 45 TMRs, described by the 19 TOs. The total inertia was 1.947, the two first factorial maps explained 41% of total inertia Results were interpreted on the first two factorial planes.

The two first axes (Fig 4 (a)) opposed intensive treatment and fertilization strategies, which can be described as conventional, with more moderate strategies. The former was closely linked to the use of hybrid varieties, high levels of fertilization and phytosanitary treatment on the left-hand side. On the right-hand side, axis 1 is linked to the use of local varieties and much more moderate input use. It also highlights weed control strategies, off-season planting strategies, or preferable fruit color at harvest. The absence of organic fertilization at the beginning of the cycle is expressed on axis 2. Axes 3 and 4 (Fig 4 (b)) express the use of ternary fertilizers and the integration of leguminous in the association. They are also associated with medium to high phytosanitary treatment classes and the highest chemical nitrogen inputs. In addition, axis 4 reflects to some extent early planting strategies, and the harvesting of both red and green fruits.

The AHC, resulting in seven clusters was carried out on the coordinates of the individuals on the four dimensions of the MCA and explained 66% of total variability. Fifteen variables contributed to the classification, consisting essentially in: planting strategies, number of pesticide applications, weeding/hoeing, harvest regularity, N, P, K, Ca, and Mg quantities, organic fertigation method, choice of variety, application or not of water stress, association with trees, association with cucurbitaceae, and use of bio-stimulant. The MCA coupled with the AHC results (Table 3) showed an opposition between conventional and chemical input intensive TMRs generally applied to hybrid varieties (cluster 1 and 2) and organic and moderate TMRs associated with local pepper varieties (cluster 5 and 6).

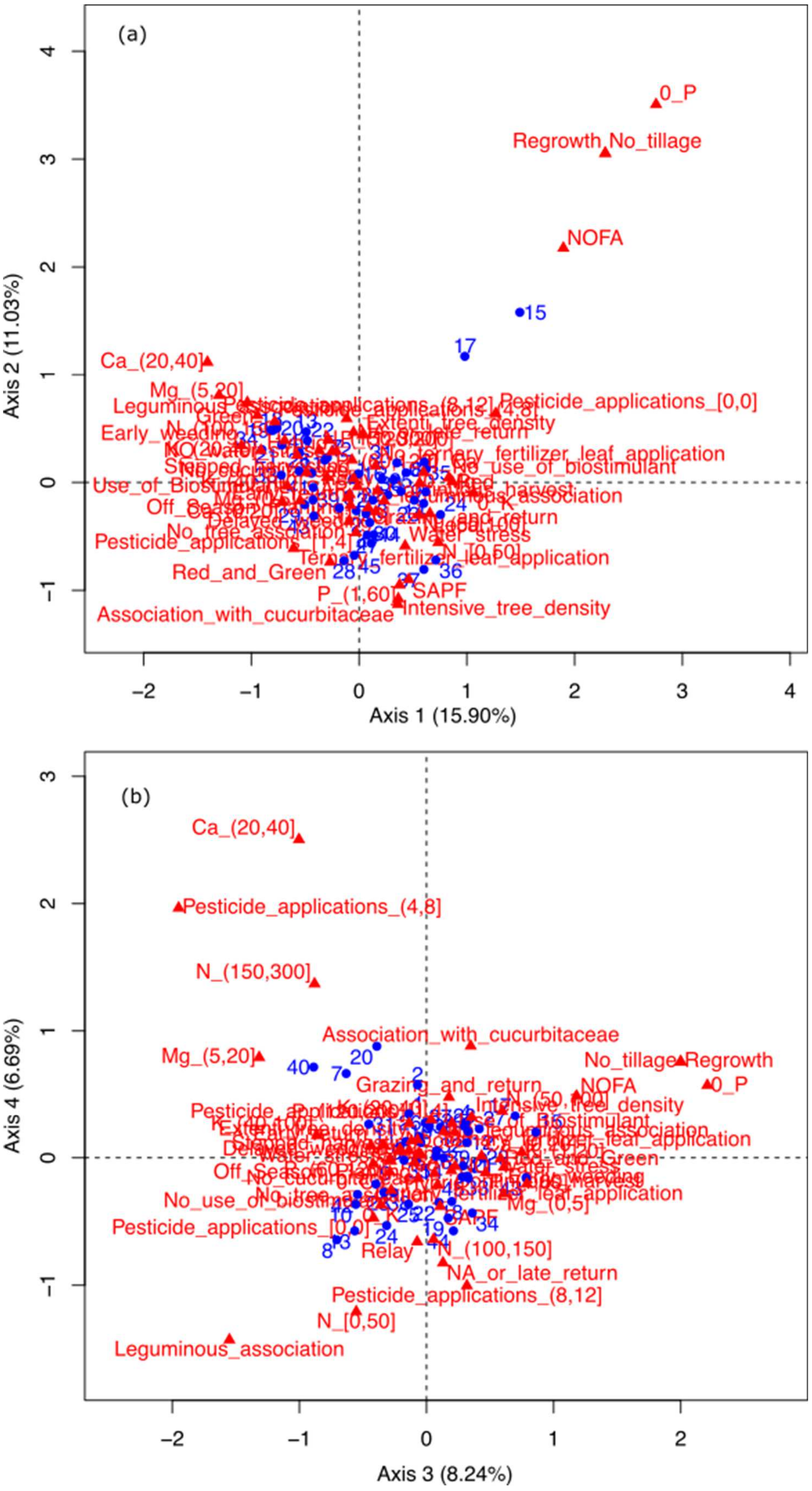

Fig. 3. MCA plot of individuals and variables (TOs) modalities

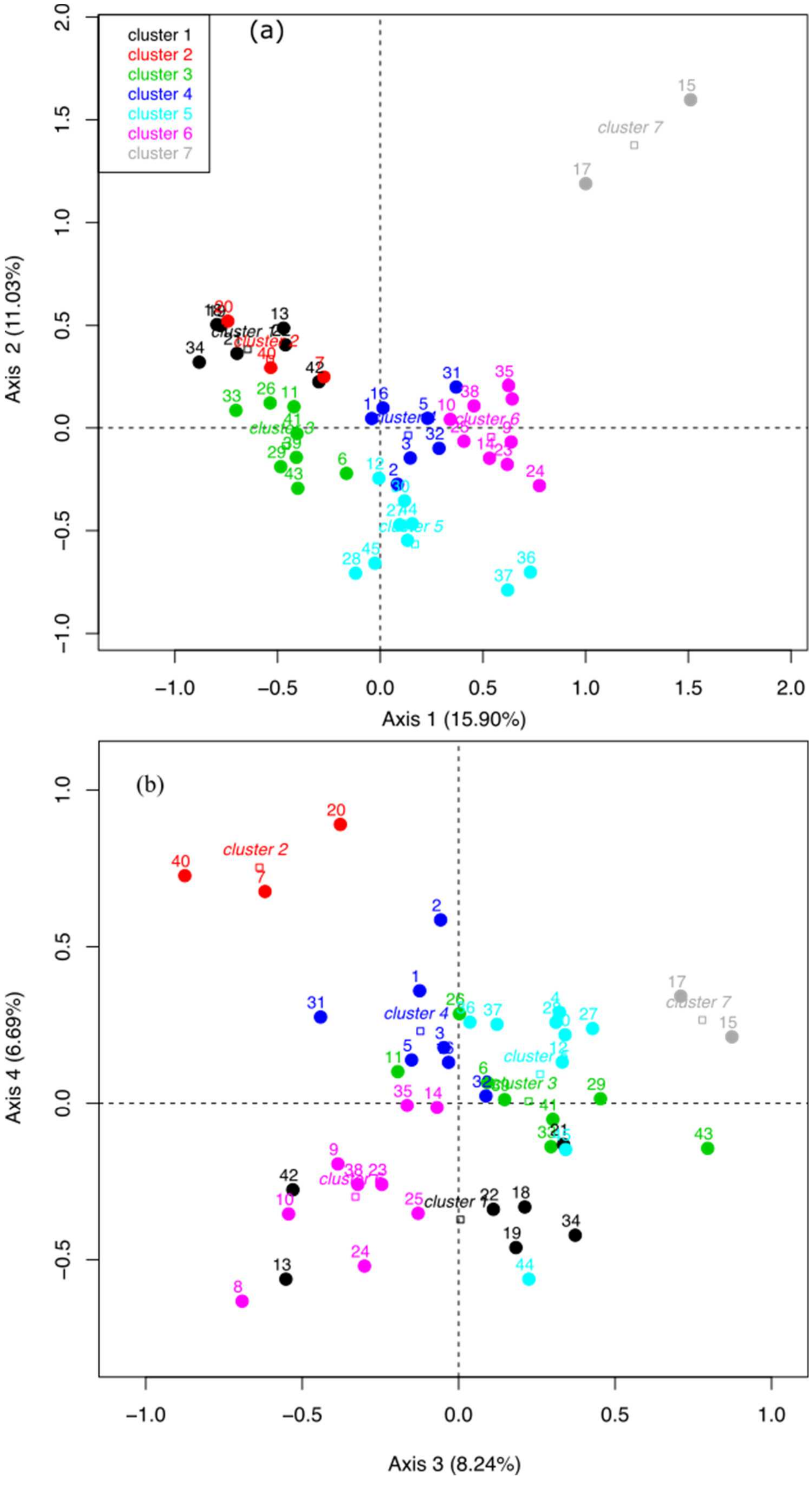

Fig. 4: factor map of (a) axis 1 and 2 and (b) axis 3 and 4 with clusters in color. The barycenter of each cluster is represented by a square

Clusters 3 and 4 could be assimilated to mixed strategies at an intermediary position between the systems of clusters 1 and 2 on the one hand, and the moderate and low-input systems of clusters 5 and 6 on the other hand. Indeed, cluster 3 contains strategies not driven by pesticide use and N inputs, potentially applied to hybrid varieties. N and P driven TMRs are present in cluster 4, potentially applied to local varieties.

Table 3: Cluster description. Modalities very significantly and significantly linked to the cluster are set in bold and italic, respectively. NOFA = No Organic Fertilizer Application, SAP = Soil Application before Planting, SAPF = Soil Application before Planting and Fertigation. Total rating: < 2: low; [2, 6[: neutral; [6, 10[: medium high; > 10: high.

Cluster name	Cluster (axes of interpretation)	Modality linked	Number of individuals	Total rating
Chemical input intensive and pesticide driven	1 (1-2-4)	**Hybrid variety, >8 pesticide applications, 100-150 kgN.ha^{-1}, off-season planting strategies, early weeding, use of synthetic bio-stimulant, no water stress, green fruit harvest.**	7	-1
Chemical input intensive and N driven	2 (1-3-4)	**5-8 pesticide applications, 150-300 kgN.ha^{-1},** *5-20 kg Mg.ha^{-1}, green fruit harvest, off-season planting.*	3	-2
Intermediary strategies	3 (1-3)	**Red and green fruit harvest,** *no tree association, <20 kg Ca.ha^{-1}, SAP.*	9	2
N and P driven	4 (4)	*150-300 kgN.ha^{-1}, 120-200 kgP.ha^{-1}, red fruit harvest.*	7	3
Moderate strategies	5 (2)	**SAPF, 1 - 60 kg P.ha^{-1}, association with cucurbitaceae, season planting, water stress application,** *1 to 4 pesticide application, 50-100 kgN.ha^{-1}, < 20 kgK.ha^{-1}.*	8	9
Very low chemical input strategies	6 (1-3-4)	**Local varieties, no pesticide application, no use of K, no use of Ca, no use of Mg, no use bio-stimulant, < 50 kgN.ha^{-1}, red fruit harvest.**	9	7
Regrowth strategies	7 (1-2-3)	**No pesticide application, no use of P**, *no tillage, regrowth, NOFA.*	2	8

3.3 Association rules and cluster

The objective of data mining, which generated the association rules, was to identify additional TOs linked to TMRs and not identified at previous steps, and to assess cluster homogeneity. Minimum support S_m was set to 0.044. The results showed that the TMRs in clusters 3, 4 and 5 were much less homogeneous than clusters 1, 2, 7 and to some extent 6. Indeed, Fig. 5 shows a large number of rules for clusters 1, 2, 7. Conversely, clusters 3 to 5 had a low number of associations. This is supported by the maximum length of rules for clusters 3, 4 and 5, which was lower compared to the other clusters. In other words, out of the 19 operations defining a TMR, there are in cluster 5, for instance, a maximum of 7 TOs common to at least half of the TMRs constituting this cluster, compared to 13 for cluster 1 and 10 for cluster 6. Additional TOs were identified through this process. These are included in the complete description of clusters presented in the following section.

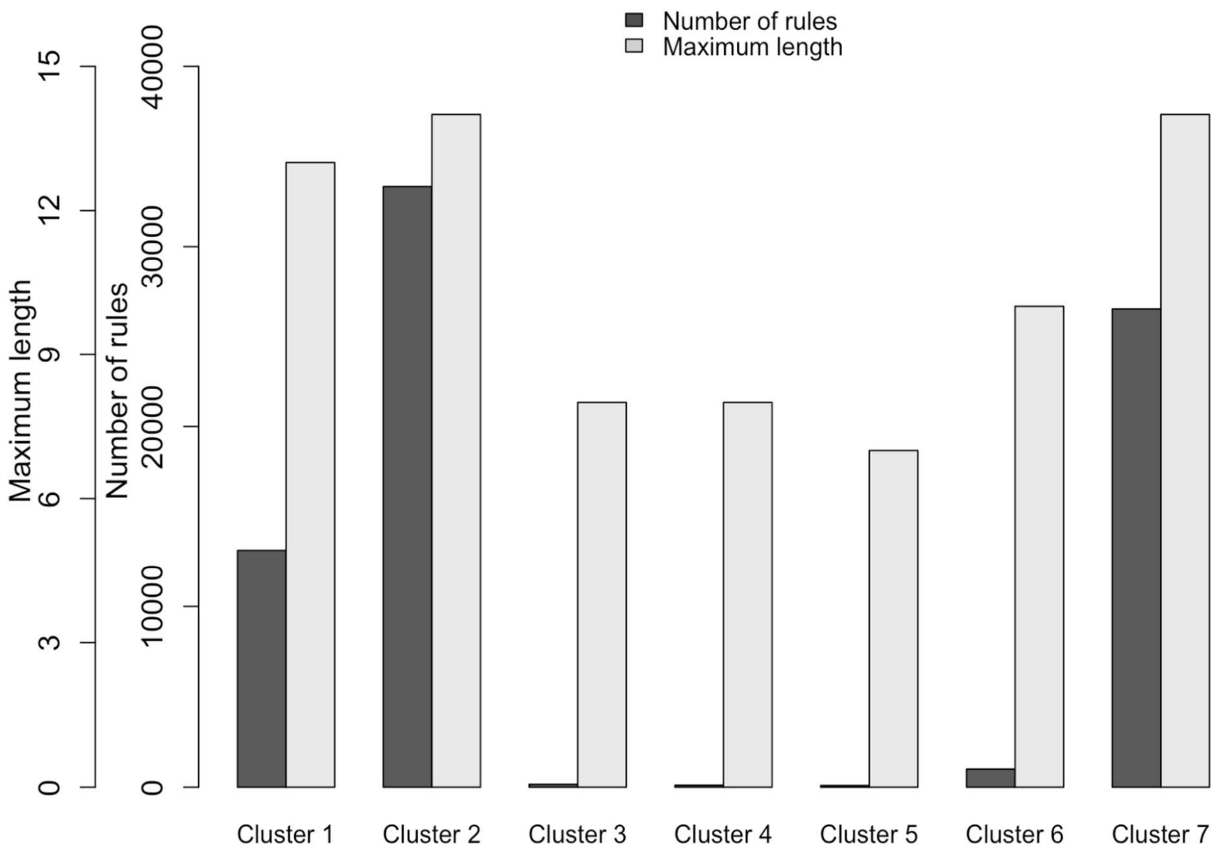

Fig. 5. Number of rules for each cluster and maximum length of rules in clusters.

3.4 Description of the seven clusters of TMRs

Figure 6 integrates the overall analysis of the results of MCA, ACH and data-mining, and shows the most representative TMR of each cluster. It shows the TOs linked to each cluster, used to compute the rating of the degree of agroecology (Table 3).

Cluster 1, constituted of rather homogeneous individuals, described a TMR using hybrid varieties, intensive in terms of pesticide applications but moderate in terms of chemical nitrogen fertilization (100 – 150 kg N.ha^{-1}). Planting is done off-season (July-August), with an early weeding. For this TMR, there is no water stress period in the irrigation calendar, harvesting is often done when the fruits are green. In addition, this cluster is characterized by the use of synthetic bio-stimulants and a late return of crop residues. The cluster 1 had a high potential impact so, these TMRs are considered as non-environmental-friendly.

Cluster 2, equally homogeneous in nature, consisted in more intensive TMRs with regard to chemical nitrogen fertilization, but moderate in terms of pesticide application. It was characterized by off-season plantation and green fruit harvesting. Further, this cluster had a high potential environmental impact, thus these TMRs are considered as non-environmental-friendly.

Cluster 3 was characterized by chili-pepper cultivation non associated to trees, the use of bio-stimulant, the application of organic fertilizers before planting and the harvest of both red and green fruits. These TMRs were mostly associated with hybrid varieties with a relatively low number of treatments (one to four treatments). They were also characterized by significant Ca and Mg inputs. Cluster 3 was very heterogeneous, particularly with regard to nitrogen fertilization, and is the only cluster not linked to any modality of this variable. This cluster had a neutral potential impact mining that these TMRs are intermediary between non-environmental-friendly and environmental-friendly TMRs.

Cluster 4 was characterized by very high chemical fertilizer inputs (150 - 300 kg $N.ha^{-1}$; 120 - 200 kg $P.ha^{-1}$, 40 - 100 kg $K.ha^{-1}$), and red-fruit harvesting. These TMRs were applied mainly to local varieties with a neutral potential environmental impact. Thus, the TMRs in this cluster are intermediary on the aforementioned agroecological scale.

Cluster 5 described systems with moderate inputs, characterized by the supply of organic fertilizers by fertigation relatively low nitrogen chemical fertilizer inputs (50-100 kg $N.ha^{-1}$) and a relatively low number of pesticide applications (<4). This cluster essentially corresponded to a TMR involved in local varieties planted in April-May. These almost always

i) comprised periods of water stress in the irrigation schedule, and ii) included association of chili-pepper with cucurbitaceae. The TMRs in cluster 5 are moderately environmental-friendly as this cluster had a medium low degree of impact.

The TMRs in *cluster 6* were very moderate in terms of chemical inputs, with no use of calcium, magnesium, potassium, nor bio-stimulant fertilizers. Chemical nitrogen inputs were very low (<50kg N.ha^{-1}), and no application of pesticides was observed. However, phosphorus inputs were high (120-200 kg P.ha-1).

These TMRs were applied to local varieties with no pest management. Fruits were harvested red. They are moderately environmental-friendly.

Cluster 7 presented an atypical farming practice. Indeed, it described management routes that were part of a two-season growing cycle, during which the residues of the first growth season were cut to initiate a second cycle by regrowth. This cluster 7 which described the second cycle, was characterized by rare interventions of the farmer, with no hoeing nor application of bottom manure at the beginning of the growth cycle. It was also characterized by a total absence of pest management. This cluster included only two individuals and is also considered as moderately environmental-friendly.

This thorough description highlights that at the territorial scale, farming practices were very diversified and contrasted. TMRs of cluster 3 and 7 were less common in the dataset. These TMRs contained very particular TOs probably rare at the territorial scale. Note that there was a wide range of alternatives to TMRs of cluster 1 and 2.

Further investigation of the potential environmental impact of the TMRs of each cluster suggests that despite this contrast, not one cluster can be seen as environmentally-friendly regarding all aspects of the TOs. Indeed, almost all the clusters were all a combination of of (non)-agroecology-compatible TOs (Fig. 6b), even though some were more moderate than others. For instance, as far as chemical fertilization is concerned, farmers commonly applied high amounts of at least one N, P or K fertilizer. At the same time, all the clusters from 1 to 5 were characterized by the use of organic fertilizers, which is an additional supply of fertilizer. Such behavior may be explained by the fact that in most cases, farmers tend to attribute a specific role to each type of fertilizer, then, the amounts applied are defined independently. Further, despite the non-environmental-friendly characters of clusters 1 and 2, they also included some agroecology-compatible TOs. The most frequent, olive grove agroforestry, which offers increased economic benefits, is often undertaken on rented land. This suggests that some farm structural information, such as land tenure, could be linked to specific TMRs.

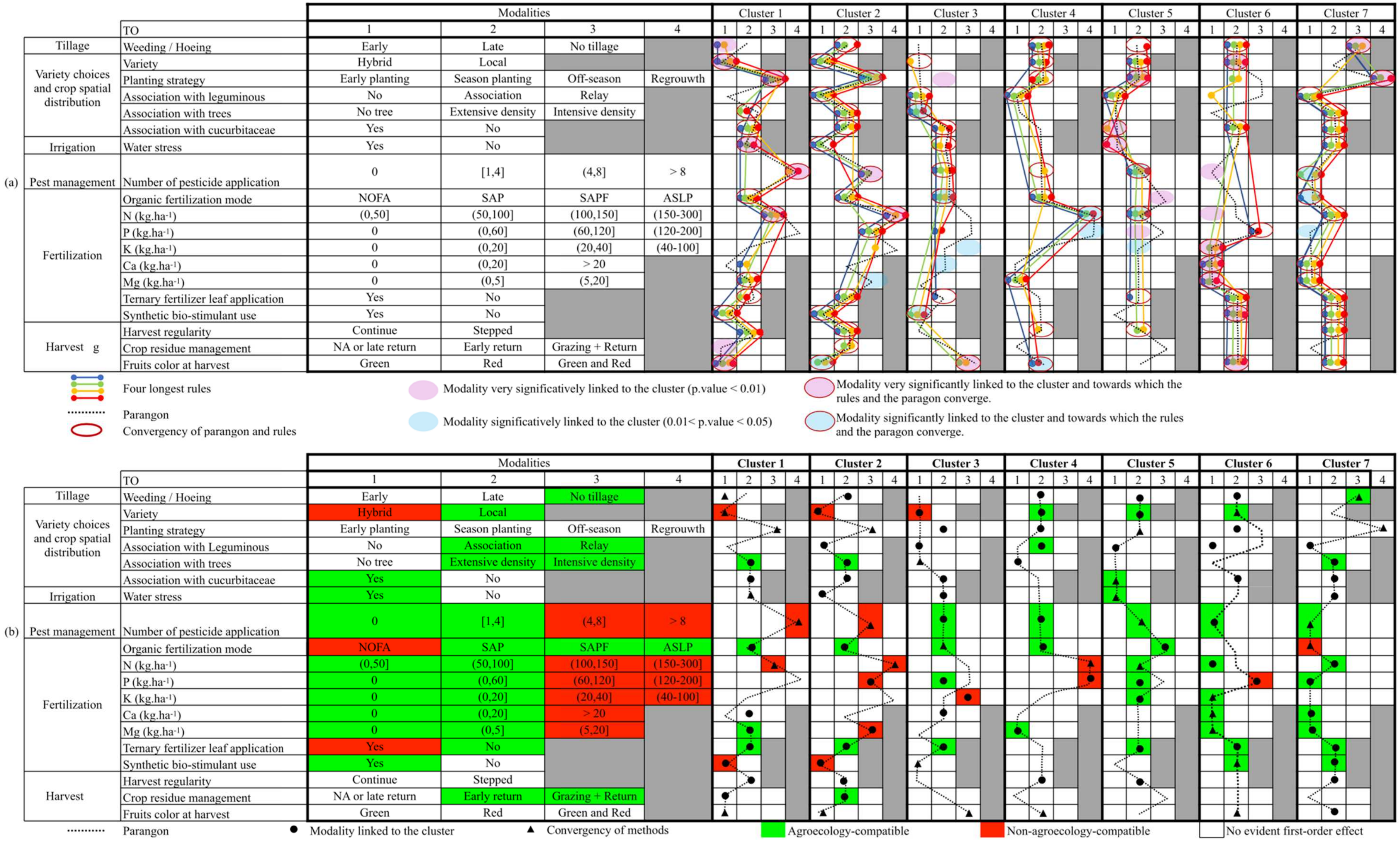

Fig. 6: Description of TMRs. (a) TOs linked to each cluster according to the three MCA, AHC and data-mining steps. (b) Schematic representation of the same results, hightling the potentially agroecological TOs according to literature.

3.5 Identifying farm types associated to each TMR

This section describes the key farm structural indicators linkable to each cluster. With the strong presence of arboriculture in the region and within the sample, Table 4 shows that this criterion characterizes the majority of farmers of all clusters. The same is true for grain farming and market garden crops in general. In addition, Table 4 distinguishes farms rather involved in environmental-friendly TMRs and those implementing non-environmental-friendly TMRs. Indeed, tenant farmers, oriented towards arboriculture, and vegetable crops of high added value, in particular cucurbitaceae (watermelon and/or melon), which consume a lot of water, were typically associated with non-environmental-friendly TMRs of clusters 1 and 2.

Table 4: Plots and characteristics of farms: for each cluster, percentage of plots located in farms having each criterion. UAA: useful agricultural area.

Cluster	1	2	3	4	5	6	7
Sample size	7	3	9	7	8	9	2
UAA (ha)	27.4 ± 25.1	51.3 ± 14.1	29.3 ± 19	15.9 ± 8.5	12.8 ± 11.8	10.3 ± 10.1	17.3 ± 20.9
Access to water							
Individual drilling (%)	86	100	78	71	75	22	50
Collective network (%)	14	0	22	29	25	78	50
Access to land							
Direct (%)	0	0	33	29	38	22	0
Indirect (%)	29	0	11	29	38	33	0
Direct & indirect (%)	71	100	56	43	25	44	100
Production							
Grain farming (%)	71	67	100	86	75	56	50
Cucurbitaceae (%)	100	100	67	86	100	78	100
Arboriculture (%)	85.71	100	100	100	87.5	89	100
Leguminous (%)	43	0	11.11	43	25	78	50
Livestock (%)	57	0	33	71	75	78	100

Due to high water needs, their access to water is almost exclusively through individual drilling. The farmers in these two groups seek maximum productivity and therefore tend to invest heavily in inputs, plant protection products and even land. They generally owned a piece of land to which rented plots were added. Consequently, their Useful Agricultural Area (UAA) might be relatively high, compared to other clusters. Since plot renting is often of short duration (1-2 years), they often do not have a long-term land management plan. This is rather the responsibility of the owner. However, tenants pay particular attention to crop history, and generally rent plots that have not been used in the previous crop year.

Land owners (“direct access” category) generally adopted TMRs of cluster 3, 4, 5, or 6. They paid special attention to crop rotation. Thus, they were often very diversified in terms of crop cultivation. In most of cases, non-environmental-friendly TMRs (clusters 1 and 2) have relatively low UAA. In addition, TMRs of cluster 6 were more likely associated to farms connected to a collective water network, that further cultivate leguminous or cucurbitaceae associated with livestock. Thus, it might possible to identify farmers adopting TMRs of cluster 6.

To sum up, a (non-)environmental-friendly field might be identified, regarding its farmer’s type of access to land. If all or most of the lands are rented and farmer has a large investment capacity, the latter might tend to have a behavior of cluster 1 and 2. If the farmer is a land owner, diversified in production, connected to a collective network with a relatively small UAA, he might have a behavior of cluster 6. It seems more complex to find a typical farm for the clusters 3, 4, 5 and 7, taken individually.

4 Discussion

This study set out with the aim of thoroughly describing farming practices in a semi-arid Mediterranean irrigated area under multiple constraints, hypothesizing that i) these constraints lead to a diversity of farming strategies and, ii) within this diversity, some interesting environmental-friendly TMRs (Technical Management Routes) adapted to these conditions could emerge. After presenting the advantages and limits of the methodology, the results are discussed relative to these aspects.

The methodology employed allowed to describe the diversity of farming practices among a diversity of farms, and we were able to identify some typical farm characteristics linked to some farming practices. The method we used to obtain these results is robust. The statistical tools used were indeed complementary and converged in most of cases. The method of typology, combining hierarchical classification and multivariate analyses, showed the main characteristics of the clusters. The data mining completed the analysis by highlighting additional TOs (Technical Operations) linked to them and their homogeneity. The points of non-convergence could be due to the interpretation criteria. Indeed, TOs present in less than half of the individuals in a cluster, whose weight in relation to the total sample is relatively high, and which are described as group specific TOs by the classical method, were not retained in the interpretation of the results. As these operations are present in less than 50% of the individuals in the group, they are not taken into account in the association rules.

Clusters 2 and 7 must be interpreted with caution because of their small size. A limit of the method is the long time required to do interviews. Another important point is that in the North African context, it is difficult to obtain reliable information on certain variables (yield, irrigation doses), in the absence of precise monitoring by the farmer.

Further, our findings support the statement that multiple TMRs can exist together in a relatively small territory, with the identification of highly contrasted clusters. It is a way to evaluate the co-existence of farming practices in an area. Our method is intended to be holistic and systemic as it integrated all the TMRs steps described by Wezel et al. (2014). Indeed, five types of management steps can be distinguished to describe a TMR: i) practices addressing crop and variety choices, crop spatial and temporal arrangements and successions; ii) tillage practices; iii) fertilization practices; iv) irrigation practices; and v) weed, pest, and disease management practices (Wezel et al., 2014). Our method also took into account the farmer's operating logics at the farm level, and the interactions between various components of this system. These have not previously been described. Indeed, much work has been done on the diversity of farms (Bellon *et al.*, 2001; Köbrich *et al.*, 2003; Maton *et al.*, 2005;

Poussin et al., 2008; Blazy *et al.*, 2009; Azizi *et al.,* 2017; Ibidhi et al., 2018), but very little on the diversity of farming practices (Renaud-Gentié et al., 2014; Czyrnek-Delêtre et al., 2018). These results are based on reliable data obtained after in-depth discussions with farmers. To our knowledge, this study is the first to implement this method on annual crops, confirming its applicability in a wider context than previous studies focused on vineyard.

The findings showed that none of the TMRs was thought in an agroecological perspective. Rather, these appear to be a combination of agroecology-(non)-compatible TOs, especially concerning fertilization practices and pesticide uses. Locally, one of the issues that emerges from these findings is that farmers commonly have a problem of fertilization management. Our study highlights the necessity for public policies, to encourage transition toward more environmental-friendly TMRs in opposition to the current tendency. Indeed, in general, it came out of discussion during surveys that TMRs likes those of cluster 1 and 2 are considered to be the “best” and “most productive” by the majority of farmers. The implementation of alternative practices is often due to economic reasons, as these are relatively less expensive. This supports previous findings showing that setting up market gardening (Azizi et al., 2017) and implementing agroecology-compatible practices (Ameur et al., 2020) are driven by the cash flow of the farms and the cost of inputs. Thus, considering the number of tenant-like farm types (mostly powering TMRs likes those of cluster 1 and 2) is increasing since last decade based on additional land rentals and high added value crops (Azizi et al., 2017), environmental-friendly TMRs may be much less prevalent in the future if no action is taken.

Furthermore, despite the high value of N inputs in clusters 1 and 2, most values observed in this study remain inferior to the optimum values presented in previous studies. Indeed, previous findings suggest that the optimum value of N fertilization to maximize the profitability of chili-pepper cultivation in drip irrigation was 252 kg $N.ha^{-1}$ (Hartz et al., 1993) and 227 kg $N.ha^{-1}$ (Zhang et al., 2010). In contrast, the observed values for P application were largely superior to theoretical requirements, in most of cases. Indeed, the optimum amount of P application for chili-pepper was estimated at 40 kg $P.ha^{-1}$ by Emongor and Mabe (2012). These are however to be taken with precaution, as pedoclimatic conditions also influence fertilizer requirements. It is important to bear in mind that the practices related to the moderate and low input clusters are not presented as agroecological systems *per se*. However, they contain a lot of single interesting and agroecology-compatible TOs. These results allow us to reassess the paradigm tending to associate irrigated agriculture to intensification and pollution. The findings provide further support for the hypothesis that smallholder farming in irrigated areas may allow the emergence of more environmental-friendly or agroecological farming practices. This study hence challenges research in agroecology in semi-arid irrigated landscapes in the Southern Mediterranean. It confirms the existence of a large range of agroecology-compatible practices at the plot level found by Ameur et al. (2020). Can these form a basis for conceiving locally-adapted, adoptable and more environmental-friendly and viable TMRs? The answer is not straightforward as the interactions among TOs and their relations with the farm-scale strategies are crucial to conceive such TMRs. At least, the high diversity of agroecology-compatible practices found in the region can be a basis towards a large-scale increase of resource-use efficiencies of existing TMRs. Thus, actions can be taken based of these practices to initiate the first steps of the Efficiency-Substitution-Redesign (ESR) process (Hill, 1998) of the agroecological transition. However, combining the agroecology-compatible practices found (such as agroforestry, leguminous integration, use of organic fertilizer etc., reduced pesticide use, use of local varieties, etc.) within new ecological-based TMRs might have social, economic and even agronomic coasts. For instance, agroforestry might generate addition income but reduce cultivated area of green market crops. The use of homemade organic fertilizers can contribute to reduce the production costs but may require increased workload. The use local varieties most resistant to pest attacks can also reduce production but in return, can also lead to lower yields. In addition, resource-use efficiencies highly depend on farmers' irrigation and fertilization strategies with have not been studied in detail. It thus remains to evaluate whether the design of ecological-based TMRs, based on the agroecology-compatible practices found, might be viable on these three axes through an agroecological assessment. More in-depth socio-economic, environmental and agronomic assessments of current and future TMRs, taking into account the whole production systems need to be undertaken.

Furthermore, our results support those observed earlier by de Lattre-Gasquet et al. (2017) describing some trends in favor of agroecological uses of land in Tunisia. The findings could allow stakeholders in charge of agriculture to better focus their action, to support smallholder farming through agroecology. Indeed, with such a diversity of farming practices, it is important to differentiate and adapt the support policies. The study can also contribute to a broader field of research on regional diversity of cropping practices. The article defined the key TOs related to each TMR and the types of farms implementing them. On the one hand, the regional representativity of these different chili-pepper TMRs could be more easily obtained by carrying rapid interviews on these key variables on a larger sample. On the other hand, the method could also be applied to the other major regional crops. The findings are also interesting for further research as far as previous studies of modeling or assessment of the environmental impact of the practices in the study zone, did not take into account this diversity (Pradeleix et al., 2012; Massuel et al., 2017; Jouini et al., 2018) or only partly (Pradeleix et al., 2018). Although the study evaluated neither the agronomic nor environmental performances of the TMRs, one simplistic assumption could be that the less environmental-friendly TMRs mostly linked to hybrid varieties lead to higher yields. Indeed, "hybrid varieties are far more productive than local varieties" according to farmers. This statement has been confirmed by additional investigations (Chloé Morel, unpublished report, 2018; Akakpo et al., unpublished data, 2019) showing that in general, yields range from less than 12 T.ha-1 for the chili-pepper local varieties to up to 70 T.ha-1 for hybrid varieties. Hence, cluster 1, 2, and 3, mostly associated to hybrid varieties can be considered as most productive, generating in general, up to 70 T.ha-1. Inversely, cluster 4, 5, 6 and 7 can be considered as much less productive, less than 12 T.ha-1, as these clusters were basically associated to local varieties. However, a mix of (non)-environmental-friendly TMRs were applied to both varieties. So, in terms of agro-environmental performance of the TMRs, one can speculate that high productivity and low environmental impacts can be achieved in systems applying environmental-friendly TMRs to hybrid varieties. Indeed, the current study, based on interviews, could not precisely take into account the outputs of the studied systems, in particular yields. The qualitative assessment of the impact of TMRs and the addition of scores of TOs different in nature and with potentially very different types of impact on the environment are a limit of the study. To have objective and realistic conclusions, this assessment requires precise monitoring of TMRs, in particular of irrigation and fertilization strategies. The paragons are typical cases that could be studied for such a purpose.

5 Conclusion

Returning to the hypothesis formulated at the beginning of this study, we can state that at the territorial scale, farming practices in the Merguelil irrigated plain are very diversified. One of the most significant findings to emerge from this study is that technical management routes of chilli-pepper crop are very contrasted. In a qualitative manner, the findings enable to answer the main question of the study by stating that environmental-friendly technical management routes exist within the conventional agriculture known for this region. Yet, farmers seem to have a common problem of fertilization management and pesticide use. The study challenges research in agroecology in semi-arid irrigated landscapes. It gives a broader hypothesis for further research to reassess paradigms tending to oppose irrigated agriculture to agroecology.

Further research might investigate the cumulative environmental impact of the studied TMRs, and their relationship to yield diversity. However, this poses a methodological problem, as it requires costly monitoring often difficult to implement in real and poorly gauged farming conditions.

Declaration of Competing Interest

None

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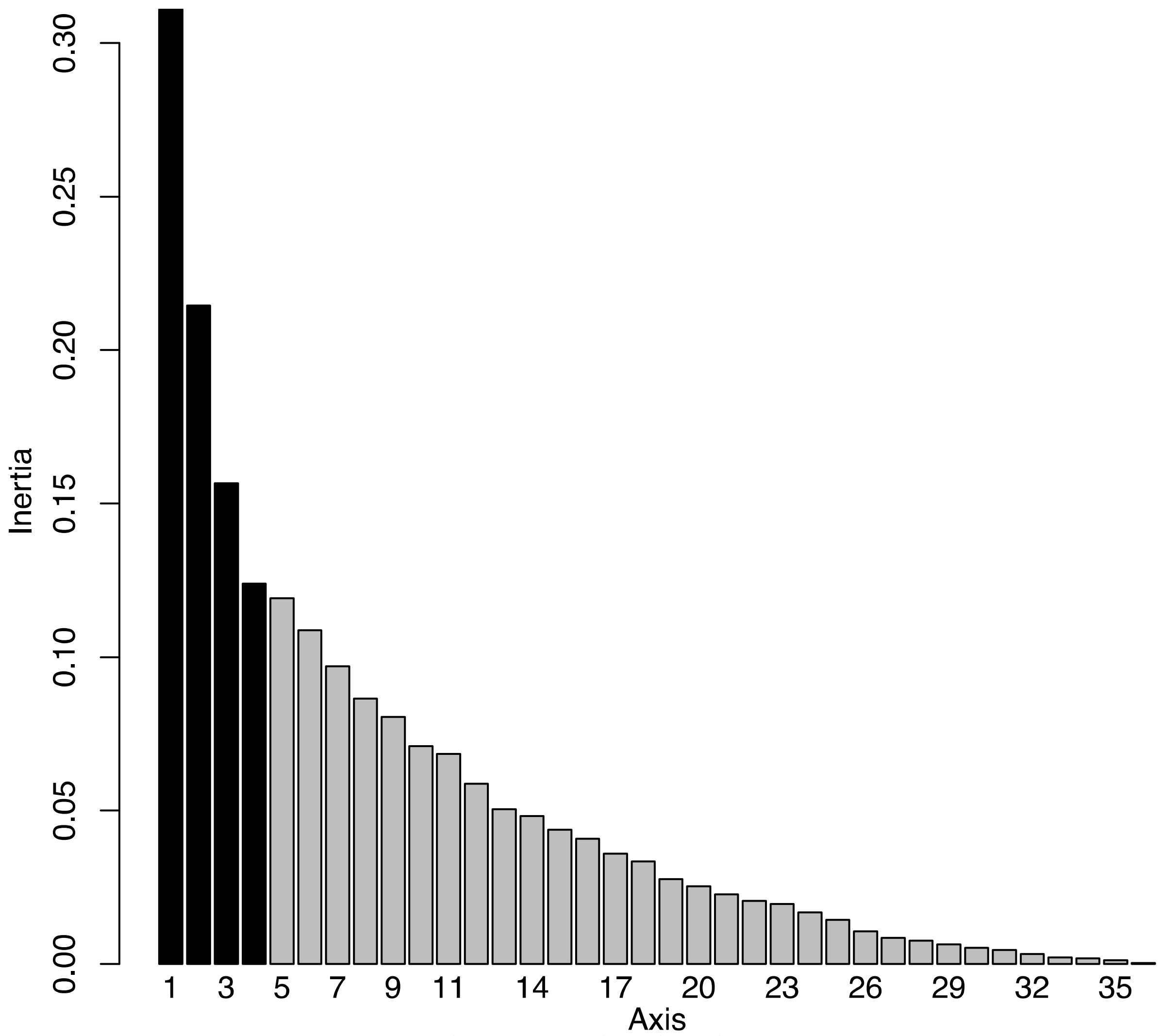
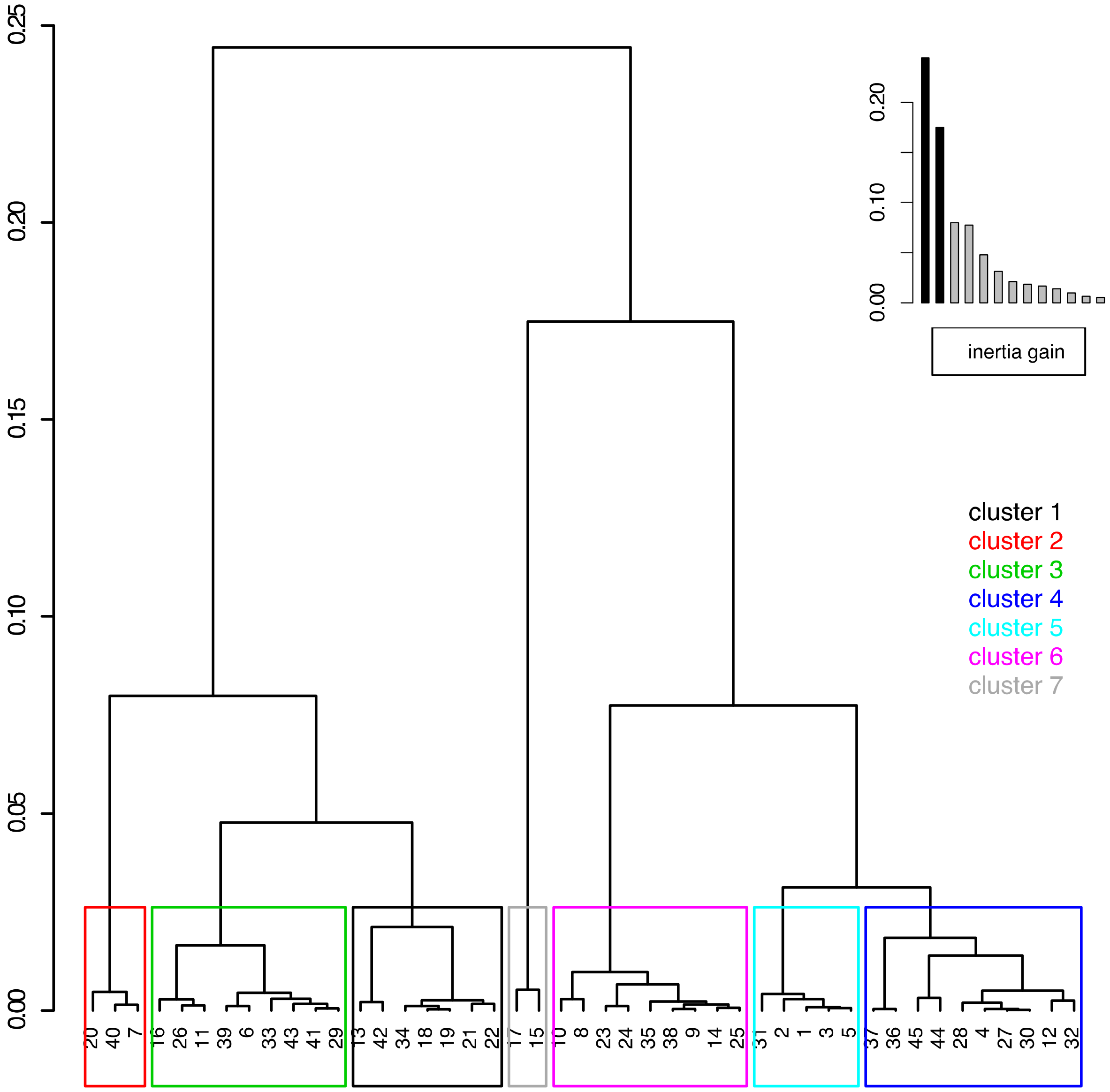
Appendix



Appendix A: MCA inertia gain chart



Appendix B. AHC tree with TMR clusters and AHC inertia gain chart